Appendix B

# Bel Marin Keys Hydraulic Modeling

# Memorandum

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| **Date:** | 18 April 2002 | **Project:** | 50273 |
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| **Company/Agency:** | Jones & Stokes | | |
| **From:** | Brad Hall | | |
| **Subject:** | Hydrologic and Hydraulic Modeling Assessment of Existing and Project Alternatives at Bel Marin Keys V | | |

***Overview***

This document presents Northwest Hydraulic Consultants (nhc) investigation of the hydraulic impact of the proposed Bel Marin Keys tidal marsh restoration project. This study quantitatively assesses the relative change of the proposed project on Pacheco Pond stages and Novato Creek stages from the Pacheco Pond outlet to the creek mouth.

The proposed tidal marsh restoration at Bel Marin Keys will affect the hydrology of several elements within the lower Novato Creek basin. Proposed modifications to Pacheco Pond and the proposed diversion of flow away from Novato Creek considered in the design alternatives will present the most substantial effects. The proposed modifications to Pacheco Pond consist of either expanding the existing pond, or creating a seasonal marsh adjacent to the pond. In addition, the diversion of water currently flowing into Novato Creek from Pacheco Pond, to the proposed tidal marsh will greatly affect existing conditions on the Bel Marin Keys tidal wetlands restoration site. These flows will provide fresh water for the proposed freshwater marsh portion of the project.

To assess the impacts of the proposed tidal wetland restoration on the hydrology of the existing site a review of hydrologic studies of the Novato Creek and Pacheco Pond watersheds was completed. Existing and proposed site conditions that affect the drainage and flooding characteristics were identified. Representative flood hydrographs and tidal stage characteristics were determined and used for computing flood stage and discharge conditions in the study area. To quantify the changes in flood stage and discharge magnitude resulting from coincident terrestrial and tidal flood conditions, a one-dimensional, unsteady flow model of the Novato Creek and Pacheco Pond system was developed. Described below are some features of this modeling effort, including a description of the basin, the proposed alternatives, the model itself, and the model results.

## ***Basin Description***

The components of the Pacheco Pond watershed consist of two small streams, Pacheco Creek and Arroyo San Jose, which drain into a constructed detention reservoir, Pacheco Pond. Pacheco Pond currently discharges into Novato Creek and finally, San Pablo Bay (Figure 1). Historically, Pacheco Creek and Arroyo San Jose discharged into the tidal marsh to the south of the Bel Marin Keys development. The specific features of the watershed are described below.

- *Pacheco Creek*

Pacheco creek drains a 1.9 square mile watershed. From the headwaters 3 miles to the west, the stream crosses several roads, including Highway 101, through a series of culverts. Flooding is known to occur in the lower reaches of Pacheco Creek, prior to entering Pacheco Pond, for flood events with magnitudes less than the 10-year event (1).

However, because this study focused on the area downstream of Pacheco Pond, the flooding of the creek upstream of the pond was not analyzed in the modeling study. Flows of Pacheco Creek into the pond were modeled as an inflow hydrograph entering the pond, as will be described below. Additional survey of channel cross sections and physical characteristics of the local storm drainage system would be required to quantify flooding conditions upstream of Pacheco Pond and within the Ignacio Business Park.

- *Arroyo San Jose*

The Arroyo San Jose watershed drains an area of approximately 5.4 square miles. Arroyo San Jose accounts for approximately three-quarters of the inflow to Pacheco Pond (2). Previous hydrologic studies of the basin indicate that the Arroyo San Jose remains within its banks for flood events up to the 100-year flood. However, accompanied with high tides in Novato Creek and the associated constriction of flow release from Pacheco Pond, the 100-year event can cause minor flooding of residential and business areas near the confluence with Pacheco Pond (1).

- *Pacheco Pond*

Pacheco Pond covers an area of approximately 120 acres. The estimated flood storage volume between elevations 0.0 and 7.0-ft, NGVD 29, is approximately 866 acre-ft. The storage volume of the reservoir was estimated from existing topographic surveys, aerial photos, and previous engineering studies. A stage-volume relation for Pacheco Pond was determined and utilized to compute the pond storage and resultant water surface elevation during storm events.

Pacheco Pond discharges into Novato Creek via a leveed channel controlled by six 4-ft by 4-ft flap gated culverts. The invert elevation of the culvert structure was independently surveyed by **nhc** and the Marin County Flood Control District to have an invert elevation of –0.86-ft, NGVD 29. It appears that the invert of the culvert was not accurately surveyed in earlier studies of Pacheco Pond hydrology, and was reported to have an invert elevation of –1.8-ft, NGVD 29 (2). The effect of the flap gate was modeled by only allowing flow in the positive direction (toward Novato Creek) through the box culvert. Minor leakage and backflow through the flap gates was not modeled in this analysis.

During high flow events the water level in Pacheco Pond can exceed adjacent levee elevations. The lowest point exists north of the pond, adjacent to the Leveroni property, where the measured low point of the levee is 5.6-ft, NGVD 29 (2). These low points were considered in the model by including lateral weirs to direct flow to adjacent storage areas when stages in the pond exceeded 5.6-ft. Top of levee surveys also indicate that a significant extent of this levee is at an elevation of approximately 6.7-ft, NGVD 29. Additional lateral overflow weirs were specified at this higher top of levee elevation in the hydraulic model.

- *Novato Creek*

Novato creek is the main drainage course in the region with an approximate total watershed area of 44 square miles (3). However, breakout flows due to flow constrictions at the railroad bridges downstream of Highway 101, and adjacent to Highway 37, reduce the overall peak flood discharge. Approximately one-half of the total peak discharge produced by the watershed is estimated to enter the lower reaches of Novato Creek below the Highway 37 bridge (4). An infinite variation in the timing of peak discharges between Novato Creek and Pacheco Pond hydrographs is possible, however, the Novato Creek peak would be expected to lag the Pacheco Pond peak due to the larger watershed area of Novato Creek. Water surface conditions within Pacheco Pond and within Novato Creek were evaluated for lag times between peak flows of zero, six, and 12 hours.

Cross sections of Novato Creek were developed by **nhc** from existing Lidar and bathymetric surveys (5). The cross sections depict the subtidal channel of the creek, adjacent tidal marsh surface, and existing levee structures that currently constrain the Novato Creek floodplain. Top of levee surveys completed in 1996, indicate that the levee crest between Novato Creek and the Bel Marin Keys V site dips to an elevation of approximately 5.6-ft, NGVD 29, at a point approximately 1000 feet downstream from the Bel Marin Keys South Lagoon navigation lock. Overtopping of this levee was observed by Bel Marin Keys residents in the February 1998 flood event. The location of this overtopping was incorporated in the hydraulic model by specifying an overtopping weir with a crest elevation of 5.6-ft, in the model geometry at this location.

- *San Pablo BayTides*

Tides in San Pablo Bay follow a mixed semidiurnal cycle, with two high and two low tides, of differing heights, occurring in a single day. Due to geographic and hydrodynamic complexities, mean tide levels vary throughout the San Francisco/San Pablo Bay system. Tide cycles in San Pablo Bay are seen to lag those at the Golden Gate by as much as 75 minutes (2). Peak tide water surface elevations in the vicinity of Novato Creek are reported as 6.0-ft, NGVD 29 for the 10-year tide and 6.5-ft, NGVD 29 for the 100-year tide (6).

Storm events lead to higher tidal stages than those predicted by gravitational forces for a variety of reasons. First, low barometric pressures associated with significant storm frontal passage leads to a regional rise in tidal stage as the oceans surface level increases in response to the reduction in overlying atmospheric pressure. Second, wind stresses may lead to a storm surge setup, further increasing peak tidal stage. Third, increases in large scale regional runoff from the Sacramento and San Joaquin watersheds, as well as contributions from San Francisco Bay watersheds, limit the low tidal excursion of normal tidal cycles. San Pablo Bay, in essence, is filled with regional runoff (7).

The tide measurements taken at the mouth of the Petaluma River were utilized to develop time series of tidal stage hydrographs at the mouth of Novato Creek. These data, completed as part of the San Francisco Airport runway expansion dredge material disposal studies, consist of tidal stage measurements recorded at 10-minute increments for the duration of approximately one month (14 June - 17 July 2000). Earlier studies of Novato Creek indicate negligible differences between Novato Creek and Petaluma River tidal stage characteristics (2). To conservatively estimate tidal conditions during flood events, these tide stage data were modified in two ways to reflect extreme tidal conditions that occur during significant flooding events. The first modification was to increase the observed peak tidal stage by one foot to reflect extreme high tides due to low atmospheric pressure and wind setup in the region. This is equivalent to coincident tidal stage boundary conditions frequently used by the Corps of Engineers and the FEMA for flood control design or flood hazard mapping studies on tidally influenced streams and rivers. The resulting peak tide is 0.25 feet lower than the 10-year peak tide. The second modification was to truncate the low tide elevation at the mean tide level to represent limits on low tide excursion due to extreme regional, basin-wide runoff conditions.

## ***Alternative Descriptions***

The descriptions of Alternatives 1, 2, and 3, given below consist of that information that is relevant to the hydrologic modeling effort. That is, only the elements that affect the hydrology and hydraulics of the site are considered. For all project alternatives, the present outlet of Pacheco Pond to Novato Creek is eliminated. Pacheco Pond will ultimately drain to the restored tidal marsh for all project alternatives. The key hydrologic characteristics of the three alternatives are described below:

*Alternative 1*

- Pacheco Pond expanded to a capacity of approximately 1241 acre-ft (above 0-ft, NGVD 29)
- flow diverted to proposed tidal marsh from Pacheco Pond through a flap gated culvert structure identical to the existing one at Novato Creek

*Alternative 2*

- seasonal wetland constructed adjacent to existing Pacheco Pond with a storage volume of approximately 1155 acre-ft (above 0-ft, NGVD 29)
- existing Pacheco Pond and seasonal wetland connected with a 100-ft wide weir, with a crest elevation of 2-ft, NVGD 29
- flow from the seasonal wetland is released to the proposed tidal marsh through a flap gated culvert structure identical to the existing one at Novato Creek

*Alternative 3*

- for the purposes of this analysis, identical to Alternative 1

## ***UNET Model Description***

To evaluate the hydraulics of the existing study basin, as well as the proposed project conditions, the hydraulic modeling program UNET was employed. UNET was developed by the U.S. Army Corps of Engineers, and provides a modeling framework for computing solutions to one-dimensional, unsteady flow problems in complex networks. The choice of using such a model was deemed necessary here due to the dynamic conditions caused by both the fluctuating tide levels in San Pablo Bay, and the rapid changes in water surface elevation expected within Pacheco Pond.

The UNET model requires hydraulic boundary conditions for both the upstream and downstream ends of the study site. For this study, the downstream boundary conditions consisted of the modified, tidal time series measured at the mouth of the Petaluma River as described above. The tidal time series data are shown in Figure 2.

The upstream boundary conditions consisted of inflow storm hydrographs. The storm hydrographs for Pacheco Creek, Arroyo San Jose, and Novato Creek were obtained from previous studies (2, 3). The hydrologic conditions considered in the analysis consisted of two scenarios. These scenarios, referred to here as A and B, are meant to loosely represent the 10-year and 100-year storm events, respectively. However, a detailed assessment of present and future watershed conditions, coincident storm peak flow analysis, and hydrologic routing characteristics that would more accurately define the expected characteristics of storm hydrographs was beyond the scope of this study. The flow hydrographs for Pacheco Creek, Arroyo San Jose, and Novato Creek for both scenarios A and B are shown in Figures 3, 4, and 5.

Theoretically, there are infinite combinations of phasing between the peak tide and the peak discharge hydrographs. To simplify the analysis, Pacheco Creek and Arroyo San Jose hydrographs were phased to be coincident with the higher high water tidal stage for all model runs. However, the phasing of the Novato Creek hydrograph was varied to investigate the effect of lag times on system. Due to the larger watershed dimensions, the peak discharge from Novato Creek would be expected to lag the Pacheco Pond peak discharges. Novato Creek hydrographs specified at three different lag times relative to the peak hydrograph from the Pacheco Pond watershed: 0-hour lag time (i.e. coincident with the higher high water tide stage and other hydrographs), 6-hour lag time (i.e. 6 hours behind other hydrographs), and 12-hour lag time. The adjustment of phasing was only relevant to the model runs that evaluated the existing conditions, as Pacheco Pond flows are routed away from Novato Creek for all project condition scenarios.

The general modeling strategy was to isolate elements within the drainage system in order to assess their relative effect on peak flows and water surface elevations. A key caveat of this analysis is that the primary consideration should be in comparing *relative* differences between computed peak discharges and water surface elevations. Detailed and consistent surveys of the physical characteristics of Pacheco Pond and Novato Creek are necessary to identify accurate, water surface elevations. These surveys were beyond the scope of this conceptual planning effort. However, *relative* differences in peak water surface elevations and flowrates between the alternative conditions assessed in this analysis are fairly insensitive to the small changes in absolute geometric conditions (e.g. plus or minus 1-foot of vertical difference in invert elevations).

Thus, the relative changes between existing and project alternative conditions can be used to assess project performance and impacts.

Four cases were considered. The first consisted of modeling the existing Pacheco Pond-Novato Creek system. The second case considered only Novato Creek, without contributing flows from Pacheco Pond, and the third and fourth cases considered only the isolated Pacheco Pond. These third and fourth cases were used to evaluate the effects and differences between Alternatives 1 & 3, and 2, on pond hydraulics. The primary assumption in the third and fourth cases is that the entire flow into Pacheco Pond will be rerouted to the proposed tidal marsh. Table 1 outlines the modeling conditions for each case.

**Table 1.** UNET Model Conditions

| Case | Model Conditions |
|---|---|
| ***Existing Novato Creek and Pacheco Pond Network -*** Evaluates the interaction between Pacheco Pond and Novato Creek for existing conditions | **Boundary Conditions**<br>• Arroyo San Jose: Scenario A and B Hydrographs<br>• Pacheco Creek: Scenario A and B Hydrographs<br>• Novato Creek: Scenario A and B Hydrographs; 0, 6, 12 hour lag<br>• San Pablo Bay: Truncated/amplified tide series<br><br>**Model Elements**<br>• Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to Novato Ck<br>• 100-ft wide lateral weir at 5.6-ft, NGVD 29 for pond overflow<br>• 1000-ft wide lateral weir at 6.7-ft, NGVD 29 for pond overflow<br>• 300-ft wide lateral weir at 5.6-ft, NGVD 29 for Novato Ck overflow to BMK site downstream of BMK community |
| ***Project Conditions on Novato Creek-*** Evaluates only Novato Creek while considering influence of added restored tidal prism downstream of BMK development. The connection with Pacheco Pond is removed from the model. | **Boundary Conditions**<br>• Novato Creek: Scenario A and B Hydrographs; 12 hour lag<br>• San Pablo Bay: Truncated/amplified tide series<br><br>**Model Elements**<br>• right bank levee removed downstream of BMK Development<br>• right bank floodplain expanded laterally by 1000-ft downstream of BMK Development to reflect opportunity for overflow into restored tidal marsh<br>• 450-acre tidal marsh modeled as storage area with hydraulic connection through new breach channel to lower Novato Creek. |
| ***Pacheco Pond Configuration for Alternative 1 & 3 -*** Evaluates an expanded Pacheco Pond with a flap gate outlet to the tidal marsh | **Boundary Conditions**<br>• Arroyo San Jose: Scenario A and B Hydrographs<br>• Pacheco Creek: Scenario A and B Hydrographs<br>• San Pablo Bay: Truncated/amplified tide series<br><br>**Model Elements**<br>• Pacheco Pond expanded<br>• Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to tidal marsh |
| ***Pacheco Pond Configuration for Alternative 2 -*** Evaluates Pacheco Pond with an adjacent seasonal marsh storage area, flow controlled by weir and flap gate structure | **Boundary Conditions**<br>• Arroyo San Jose: Scenario A and B Hydrographs<br>• Pacheco Creek: Scenario A and B Hydrographs<br>• San Pablo Bay: Truncated/amplified tide series<br><br>**Model Elements**<br>• Additional 650-acre storage area attached to Pacheco Pond to simulate constructed seasonal wetland<br>• 100-ft wide inline weir to control flow from pond to seasonal marsh<br>• Six 4-ft tall by 4-ft wide, unidirectional box culvert controls flow to tidal marsh |

*Model Results*

The UNET model results of primary interest are the effects of the proposed tidal restoration on the stage within Pacheco Pond and Novato Creek. With respect to the former, comparison between the stage hydrographs within the existing pond (Figs. 6 and 7) and those of those of Alternatives 1 & 3, and 2 (Figs. 8 and 9), show that the proposed changes will substantially reduce peak water surface elevations within Pacheco Pond (Table 2). This reduction in Pacheco Pond elevations will have a positive benefit on Ignacio Business Park drainage conditions that are presently aggravated by high stages within Pacheco Pond. The magnitude and extent of this improvement to local storm drainage conditions, however, was not quantified in this analysis.

**Table 2.** Peak Water Surface Elevations in Pacheco Pond (ft, NGVD 29)

| Case | Scenario A | Scenario B |
|---|---|---|
| Existing | 6.4 | 7.6 |
| Alternative 1 & 3 | 4.5 | 7.2 |
| Alternative 2 | 4.6 | 6.3 |

Also of interest are the effects of the proposed project on stages within Novato Creek. Under the project alternatives being considered for the Bel Marin Keys tidal wetland restoration, all flow from Pacheco Pond will be diverted away from Novato Creek and routed through new drainage structures into the proposed tidal marsh. To examine the effect of this diversion, stage hydrographs at select locations along Novato Creek are presented in Figures 10 and 11, for scenarios A and B, respectively. The locations chosen include the upstream limit of the model at Highway 37 bridge (CS 10), at the existing confluence of Pacheco Pond with Novato Creek (CS 8), and just downstream of the lower Bel Marin Keys navigational lock (CS 4).

The stage hydrographs shown in Figures 10 and 11, suggest that peak water surface elevations within Novato Creek are controlled primarily by tidal fluctuations. That is, the effects of diverting Pacheco Pond flow, in addition to the added tidal prism created by the constructed tidal marsh, do not substantially change the peak water surface elevations between existing and project conditions. The changes that do occur are a negligible drop (less than 0.1 foot) in peak stage when Pacheco Pond flow is diverted.

***References:***


1. Jones & Stokes Associates Inc., 1998 (December), "Hamilton Army Airfield Wetland Restoration, Final EIR/EIS" California State Coastal Conservancy, and U.S.A.C.E, S.F.

2. Philip Williams & Associates Ltd., 1998 (October), "Appendix E: Hamilton Base Realignment & Closure, Wetland Conversion Alternative: Airfield Panhandle Flood Assessment", Prepared for IT Corp.

3. U.S. Army Corps of Engineers, San Francisco District, 1987, "Hydrologic Engineering Report, Novato Creek and Adjacent Streams", City of Novato, Marin County, California.

4. CSW/Stuber-Stroeh Engineering Group Inc., 1996 (January), "Bel Marin Keys V Master Storm Water Management Plan", Prepared for the Presidio Group.

5. Towill, Inc. 1996. “Hydrographic Survey of Novato Creek performed on July 31 and August 1 for the Bel Marin Keys Community Services District.” San Francisco, CA.

6. San Francisco District, Corps of Engineers, 1984. “San Francisco Bay, Tidal Stage vs. Frequency Study,” San Francisco, CA.

7. Charles D. Anderson, Katherine M. Oven, Christy Chung, 2000. “Surf’s Up – or Tide Cycles During Storm Events.” Spring 2000 Floodplain Managers Association Conference, San Diego, CA.

**Figures**

Figure 1.  Site Map

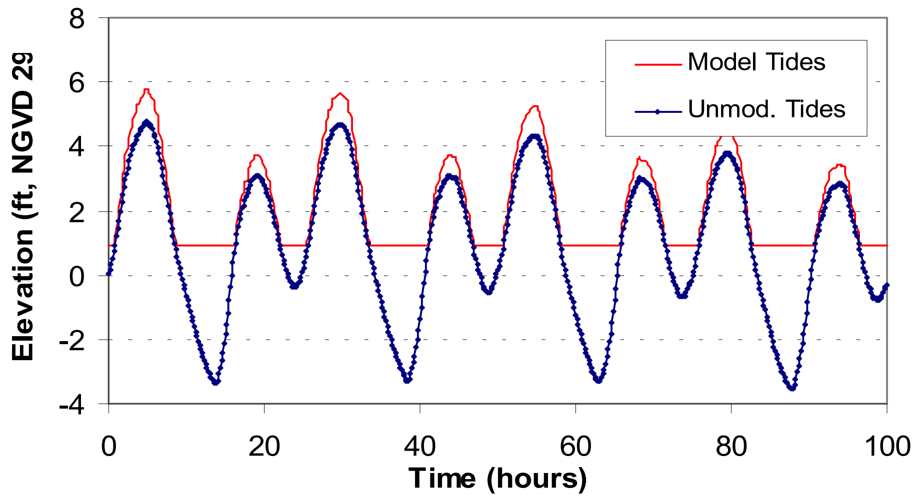



**Figure 2.** Unmodified tide series, and tide series used in UNET model

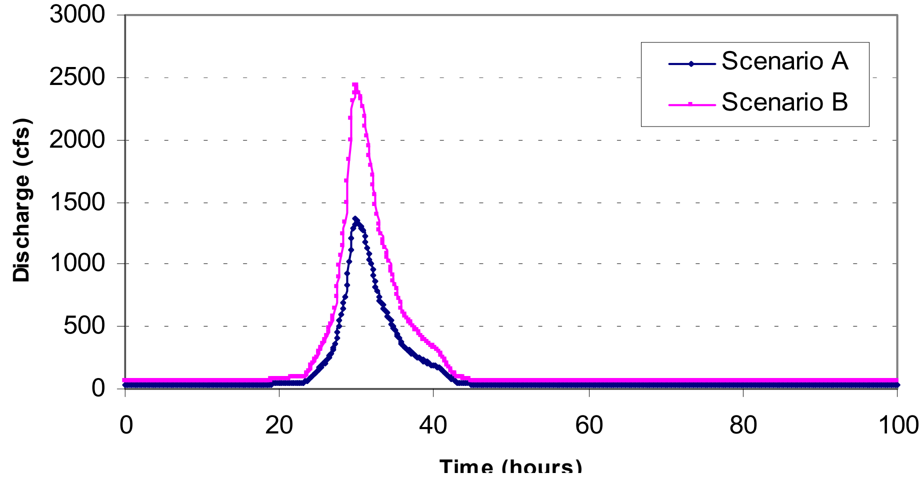



**Figure 3.** Arroyo San Jose Input Hydrographs

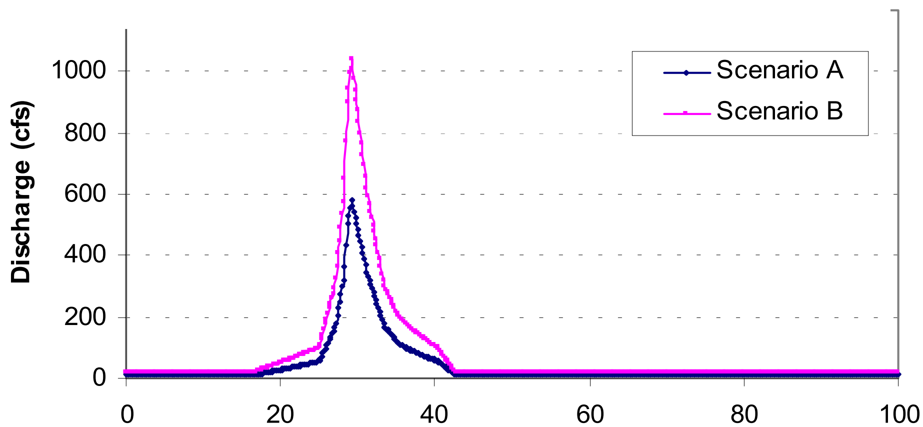



**Figure 4.** Pacheco Creek Input Hydrographs

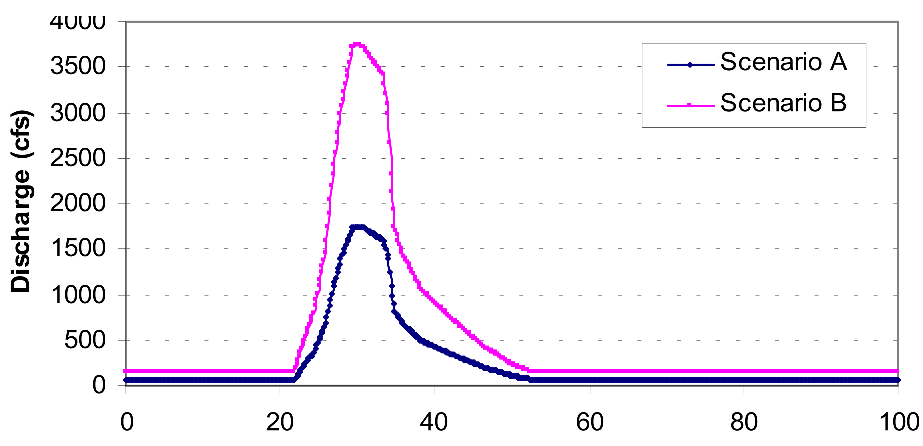



**Figure 5.** Novato Creek Input Hydrographs (0-hour lag)

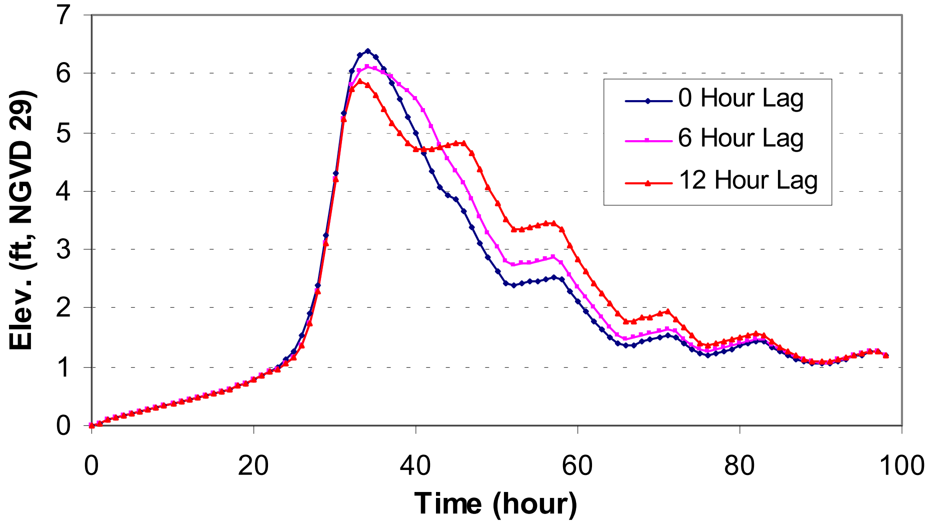



**Figure 6.** Pacheco Pond water surface elevations, existing conditions, Scenario A

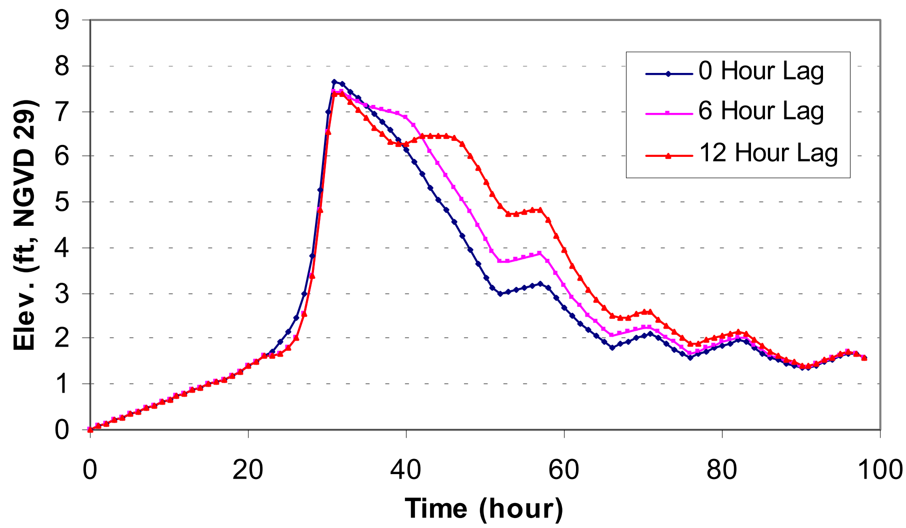



**Figure 7.** Pacheco Pond water surface elevations, existing conditions, Scenario B

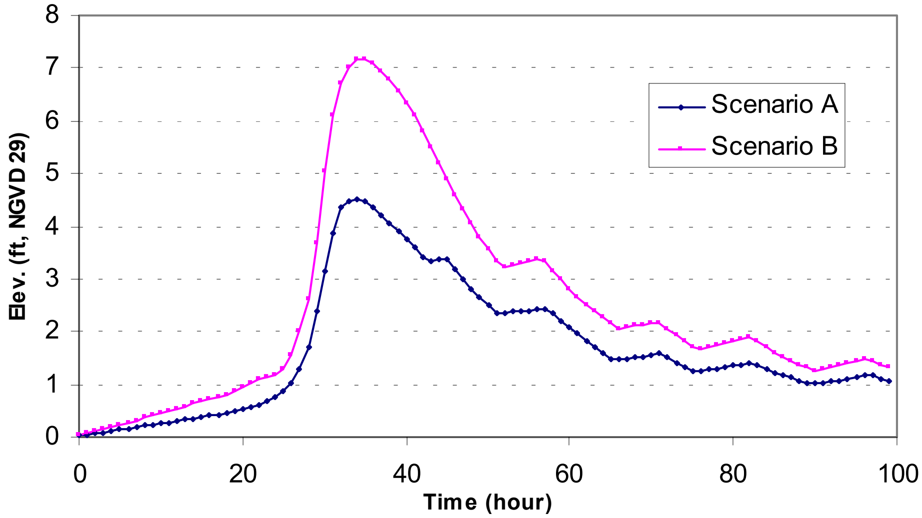



**Figure 8.** Pacheco Pond water surface elevations, Alternatives 1 & 3

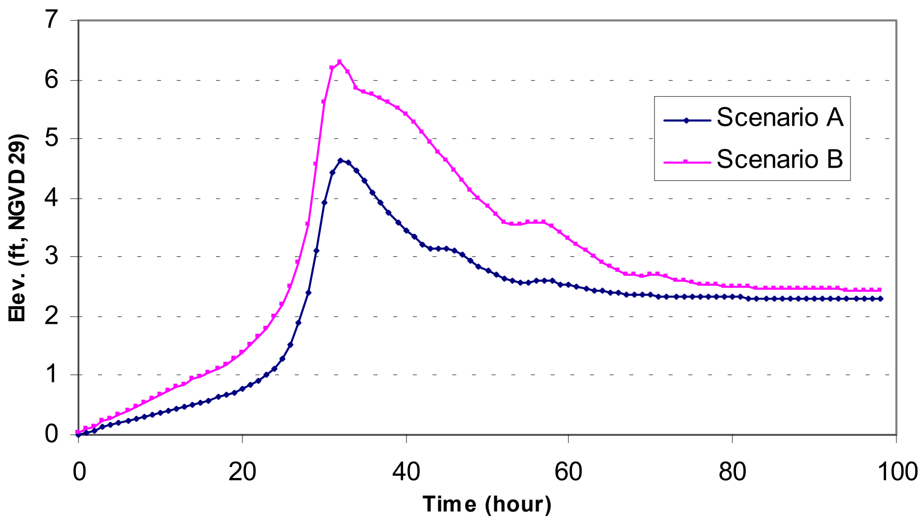



**Figure 9.** Pacheco Pond water surface elevations, Alternative 2

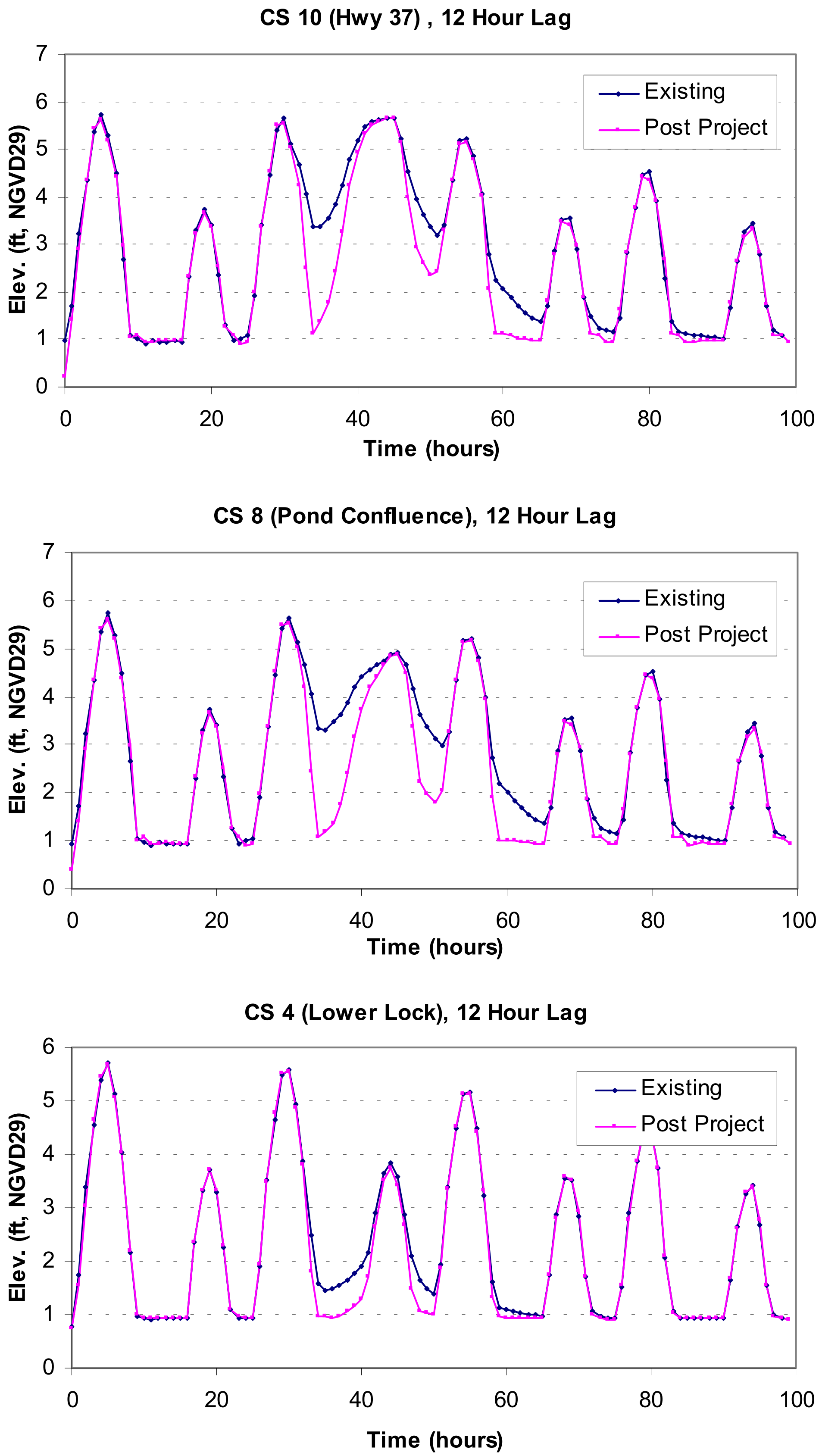
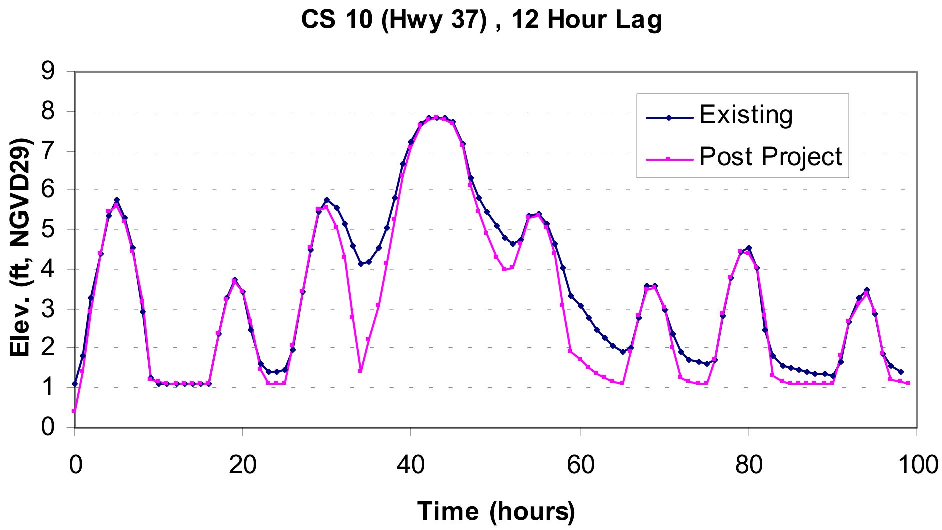
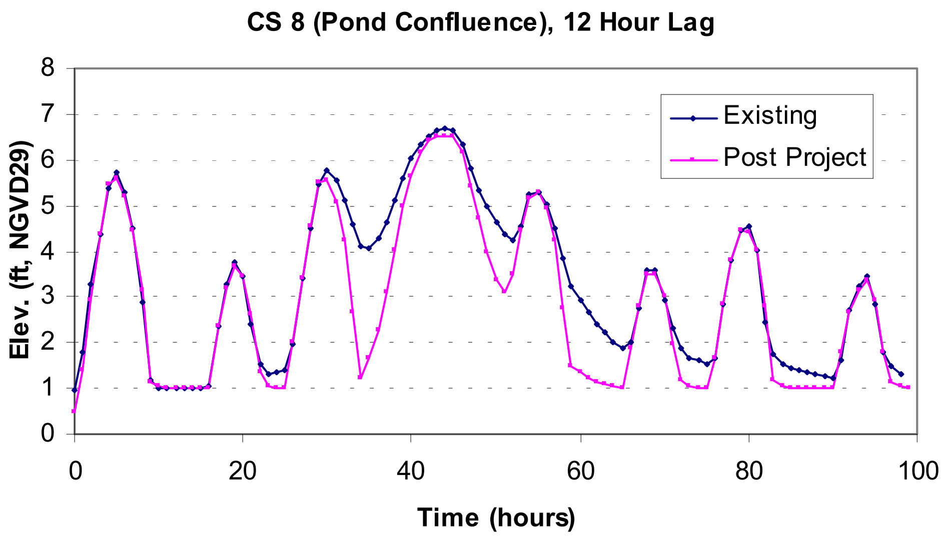



**Figure 10.** Stage hydrographs at select locations along Novato Creek, Scenario A



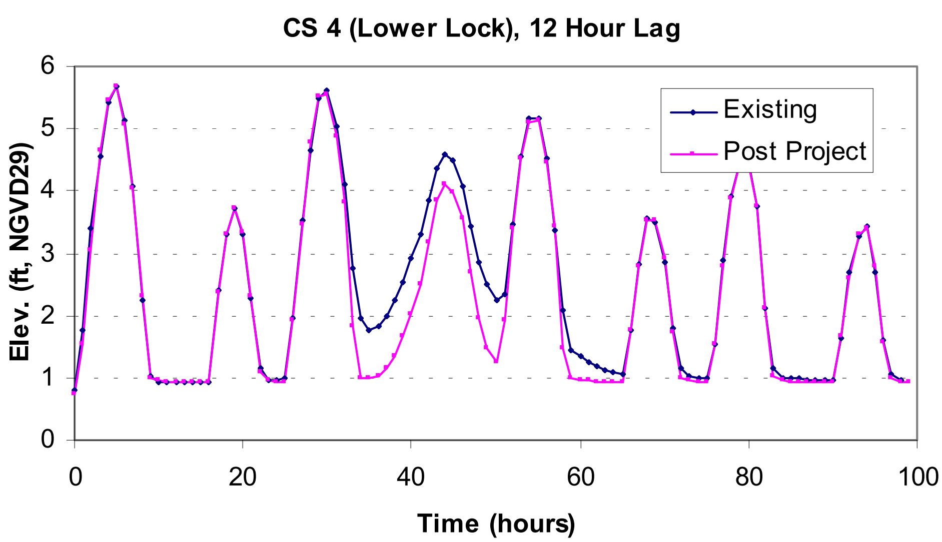




**Figure 11.** Stage hydrographs at select locations along Novato Creek, Scenario B

# Memorandum

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## Novato Creek Geomorphic and Hydraulic Modeling

The Bel Marin Keys (BMK) conceptual design plans call for a breach in the Novato Creek containment levee to provide tidal exchange to a proposed marsh basin near the mouth of the creek. The addition of the basin to the existing system would enlarge the tidal prism of the creek and increase the tidal discharge in the channel reach between the breach and San Pablo Bay. To better understand the effects of the proposed breach, an unsteady hydraulic model of Novato Creek was developed and tested. Also, an empirical investigation of the surrounding shoals at the mouth of the creek was implemented. This memorandum discusses the background, methodology, and general results of these investigations.

### Novato Creek Modeling Approach

UNET, a one-dimensional hydraulic model developed by the U.S. Army Corps of Engineers, was used to determine channel velocities in Novato Creek from tidal exchange. The marsh basin was specified as a storage area connected to the creek by the levee breach. The time series tide data used for the analysis were measured by ADEC and obtained at the mouth of the Petaluma River. Measurements were taken at 10-minute intervals over a full month period during the summer of 2000. The data was adjusted slightly so that mean sea level of the data correlated with the observed mean sea level of San Pablo Bay at the mouth of the Petaluma River (0.62 feet NGVD). No adjustments were made to the data to account for frequency or lag effects.

Cross sections for Novato Creek were developed from an algorithm that related slough channel top width to channel side slope and base width. This relationship was created by Northwest Hydraulic Consultants using data from various sloughs and channels located in the San Francisco Bay area, including Novato Creek. The equations relating the hydraulic parameters were of the form:

$$m = m_1 T^{m_2} \tag{1}$$

$$b = b_1 T \tag{2}$$

where *m* and *b* are the typical channel side slope and base width, respectively, associated with a top width *T*. The constants $m_1$, $m_2$, and $b_1$ were determined to be 0.13, 0.67, and 0.5, respectively, such that the hydraulic characteristics of the predicted and observed cross sections were as similar as possible. Equations 1 and 2 were then used to estimate the existing and likely future geometries of Novato Creek during the hydraulic and geomorphic modeling processes.

The modeling procedure for estimating the widening of Novato Creek was an iterative process. Using the 30-day tide data and UNET, channel velocities and water surface profiles were calculated in the creek. This information was used to estimate shear stresses that developed along the bed at each time step. Each shear stress, in turn, was used to estimate the incremental erosion that would take place along the channel according to the empirical equation:

$$E = M \frac{t - t_{cr}}{t_{cr}} \tag{3}$$

where *E* is the erosion rate, $\tau$ is the average boundary shear stress at a cross section, $\tau_{cr}$ is the critical shear stress for erosion, and *M* is an erosion coefficient.

A wide range of values is presented in the literature for the erosion coefficient. The values ranged from a low of 0.003 $g/m^2s$ found by Mehta et al. (1994) to a high of 5.0 $g/m^2s$ calculated by Ariathruai and Arulanandan (1978). In an effort to establish a suitable value for *M*, erosion data were obtained from slough channels between the years of 1994 to 1998 at Sonoma Baylands (Phillip Williams and Associates, 1999) and 1997 to 1999 at the Oro Loma Marsh (Lenington, 2001). From analysis of the data, an erosion constant of *M* = 0.015 $g/m^2s$ was established, which produced erosion rates of about 0.5 to 3 feet per year in channels with peak velocities between 3.5 and 6 feet per second.

Critical shear stress is a function of many variables including the physical and chemical properties of the eroded soil, and density and type of vegetative cover. A midrange value of $\tau_{cr}$=0.75 $N/m^2$ was adopted as a reasonable compromise. This value also produced modeling results that agreed well with the stable channel threshold velocity range of 2.5 to 3 feet per second.

Channel roughness in UNET is modeled using the Manning Equation and an associated Manning's 'n' coefficient. The coefficient accounts for hydraulic energy losses due to friction, which are responsible for the phenomenon of tidal muting. An appropriate value for Manning's n was developed using both published values and an empirical calibration of the Skaggs Island UNET model. Weisman et al. (1989) calculated coefficient values that ranged between 0.0125 and 0.0202. Chow (1959) listed values of 0.020 to 0.025 for channels made of fine silts and clays. Barnes (1967) suggested a value of *n*=0.026 for the Indian Fork River, which has a clay channel and a flat slope. Leopold et al. (1993) found somewhat higher roughness values for local tidal channels that ranged between 0.028 and 0.063.

For this study, Manning's n was determined by trial and error using tide data collected by ADEC (2000) and Warner and Schoellhamer (1999). Both data sets include tide data collected at the lower end of Sonoma Creek and at Hudeman Slough at the northern end of Skaggs Island. The data indicate that full tidal exchange occurs at both stations, with a lag time of about 30 to 40 minutes. With this in mind, a UNET model of the existing slough network around Skaggs Island was developed specifically to calibrate Manning's n for the system. By trial and error, it was observed that tidal muting disappeared in the model when using a roughness coefficient of n=0.02. This value was, therefore, defined as the slough channel roughness coefficient. The marsh plains were assumed to be much rougher than the channels due to dense vegetation and variable topography. A value of n=0.04 was assigned to these areas according to Barnes (1967), Chow (1959), and engineering judgment. UNET model results were relatively insensitive to the value of the marsh plain roughness.

### Mudflat Modeling Approach

To estimate the potential effects of the proposed restoration on the mudflats, or shoals, at the mouth of Novato, a study of existing mudflat channels was performed. This study consisted of using bathymetric data and newly established transects in established mudflat channels around the bay to develop a relationship between mudflat channel top width and upstream tidal prism volume.

Typical mud flat cross sections were selected where the average mud flat elevation was approximately -0.5 m, NGVD 29. Tidal prism volumes in the upstream basins were estimated using the planform area of the observed channels multiplied by the vertical range in tides (MHHW to MLLW). Figure 1 presents the relationship observed between mud flat channel width and upstream tidal prism volume. A best-fit linear curve as added to the data points and used to estimate future mud flat channel sizes as a function of increased tidal prism volume.

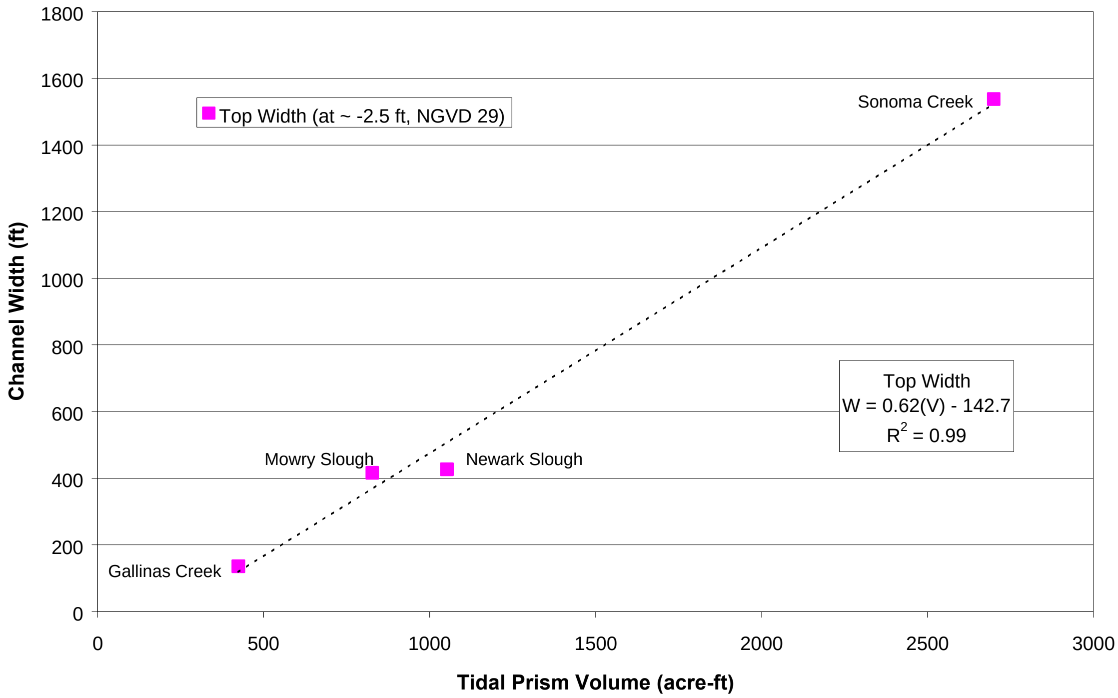


**Figure 1.** Mudflat channel width as a function of upstream tidal prism volume.

## Modeling Results and Discussion

The hydraulic and geomorphic modeling of the lower Novato Creek suggested that the channel would increase between 10 to 25 feet in width due to the addition of the proposed marsh basin connection. This corresponds to about 10 to 20 acres of eroded marsh flood plain. The shoal analysis predicted a loss of approximately 10 to 15 acres of existing mudflat due to the basin connection. However, the restoration project is expected to develop 350 acres of new tidal marsh and over 50 acres of new fringe mud flat. Therefore, these impacts are considered to be less than significant.

The velocity increases predicted by the hydraulic model in the main Novato Creek channel were themselves relatively small. These increases diminish quickly as the flow spreads over the flood plain and are undetectable at the level of resolution for the completed BMK studies at levee boundaries. Therefore, the velocity increase would not threaten the structural integrity of the confining levees.